Final Report

(4/20/05)

Project Title: Error Covariance Estimation for Mesoscale Data Assimilation

ONR Award No.: N000140210453
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Principal investigator: Qin Xu

Long-term Goals

Explore and develop new ideas and methods of error covariance estimation that will provide necessary statistical descriptions of prediction and observation errors for mesoscale data assimilation.

Objectives

Improve the existing innovation method to estimate prediction and observation error variances and their station-to-station variations. Evaluate and quantify the non-homogeneous and non-isotropic aspects of prediction error covariance. Fulfilling these research objectives should lead to fundamental contributions to the development of mesoscale data assimilation, especially for incorporating remotely sensed high-resolution data (such as Doppler radar wind data) into the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) using the recently developed Navy's Variational Data Assimilation System (NAVDAS) and the recently delivered software packages (from CIMMS at the University of Oklahoma to the Naval Research Laboratory, Marine Meteorology Division at Monterey) for radar and GOES satellite data assimilation.

Approaches

The conventional innovation method is robust but does not estimate horizontal variations of error variances mainly because it assumes implicitly that the ratio between the observation error variance and prediction error variance is independent of observation stations. This assumption facilitates the statistical analysis but is not indispensable. A new approach can be developed to partition the innovation variance into prediction and observational error variances for each observation station by relaxing the above assumption. The horizontal variations of prediction and observational error variances can be then estimated.

To optimally assimilate Doppler radar radial-velocity observations into a numerical model, it is necessary to estimate their error statistics. No method existed for this. A new statistical method can be developed to estimate the required error covariances from radial-wind innovation data by constructing necessary non-isotropic forms of radial-velocity error covariance for statistical analyses of radar radial-wind innovation data.

Major research activities and accomplishments

1. New innovation data were collected from the Navy Operational Global Atmospheric Prediction System (NOGAPS) in collaboration with scientists at NRL Monterey. By normalizing the innovation data station-by-station, the conventionally assumed horizontal homogeneity for the forecast background error covariance (in the innovation method) was relaxed, so the background error correlation was modeled directly by a truncated spectral expansion of Bessel basis functions. Generalized spectral expansions were then constructed by bi-quadratic spline basis functions on finite-element meshes to model the horizontal variations of the background error standard deviations (square roots of the error variances). The spline model was combined with the error correlation model into a hybrid spectral representation of the background error covariance. When this representation was used to fit the innovation data, the minimization problem became nonlinear. Thus, an iterative scheme was designed to minimize the costfunction alternately in two subspaces of the model parameters: one is the subspace composed of the correlation model parameters and the other is the subspace composed of the spline model parameters. To ensure and improve the convergence of the iteration, a smoothness constraint was designed and applied to the spline model. The iterative scheme was coded with the smoothness constraint and tested successfully with newly collected NOGAPS innovation data. Examples are shown in Figs. 1 and 2 for the estimated error statistics for the period from March to May 2000. The results were presented at the *Roger Daley Memorial Symposium* (Xu et al. 2003a).

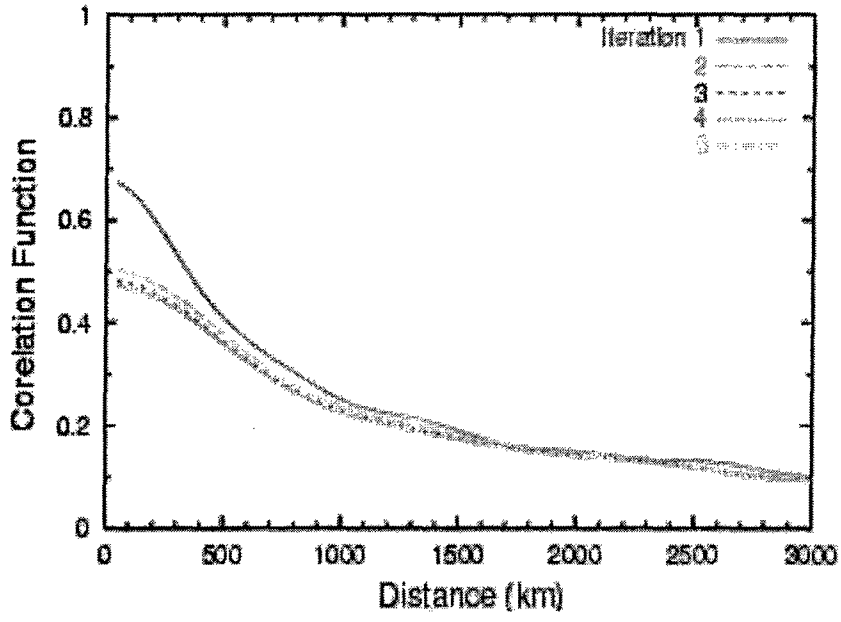

Fig. 1. NOGAPS 850 mb height forecast background error correlation functions estimated through five iterations.

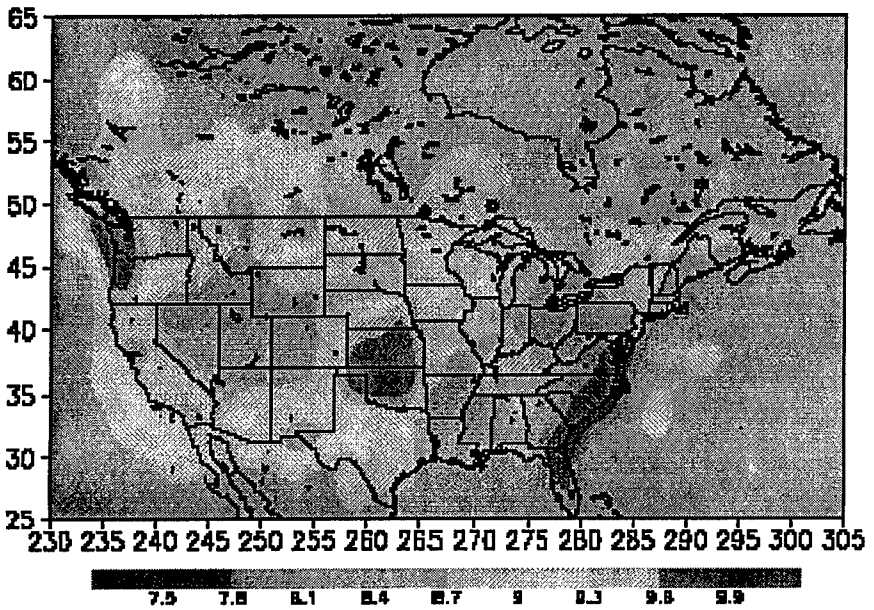

Fig. 2. NOGAPS 850 mb height forecast background error standard deviation (m) estimated at the final step of iteration.

2. A non-isotropic form of error correlation function was derived and coded for radar radial-wind analysis on conic surfaces of radar scans (Xu and Gong 2002). Based on this form of error correlation function, a method of statistic analysis was developed to estimate background wind error covariance and radar radial-wind observation error covariance from radar radial-wind innovation data. Independent Doppler radial wind observations were collected from the OKC airport TDWR radar (through necessary data quality controls) while background vector winds were provided by real-time retrievals from KTLX radar (Liu et al. 2002, Zhang et al. 2002). Time series of innovation radial-wind fields were given by TDWR radial winds minus the background winds projected on each radar beam at each range gate (with a resolution of 150 m). The method was applied to these (and many other) innovation radial-wind fields and produced very encouraging results (Xu et al. 2003b).

Publications

Xu, Q., and J. Gong, 2002: Background error covariance functions for Radar wind analysis. Preprints, *19th Conference on Weather Analysis and Forecasting and 15th Conference on Numerical Weather Prediction,* 2 - 16 August, 2002, San Antonio, TX, Amer. Meteor. Soc., 286-287.

Liu, S., C. Qiu, and Q. Xu, 2002: A variational method for dual-Doppler Radar retrievals of wind and thermodynamic fields. Preprints, *21th Conference on Severe Local Storms,* 2 - 16 August, 2002, San Antonio, TX, Amer. Meteor. Soc., J145-146.

Zhang, P., Q. Xu, and A. V. Ryzhkov, 2002: Identification of biological scatters and Radar

data quality control. Preprints, *21th Conference on Severe Local Storms,* 2 - 16 August, 2002, San Antonio, TX, Amer. Meteor. Soc., 208-209.

Xu, Q., and J. Gong, 2003: Background error covariance functions for Doppler radial-wind analysis. *Quart. J. Roy. Meteor. Soc.*, **129**, 1703-1720.

Xu, Q., K. Nai, A. VanTuyl and E. Barker, 2003a: New statistical analyses of innovation vectors. Presented at *Roger Daley Memorial Symposium*, 28 Sept.-1 Oct. 2003, Montreal, Canada. To be reported by a journal paper (in preparation).

Xu, Q., L. Wang, and K. Nai, 2003b: Error covariance estimation for Doppler wind data assimilation. Preprints, *31th Conference on Radar Meteorology*, 6–12 August 2003, Seattle, Washington, Amer. Meteor. Soc., 108-109.

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14. ABSTRACT
The goal of this project is to explore and develop new methods of error covariance estimation that will provide necessary statistical descriptions of prediction and observation errors for mesoscale data assimilation. To this end, two research objectives were fulfilled: (i) The previous method of innovation (observation minus forecast) vector analysis was extended to estimate horizontal variations of prediction and observational error variances. The extended method was successfully tested with newly collected innovation data from the Navy Operational Global Atmospheric Prediction System. (ii) A non-isotropic form of error correlation function was derived for radar radial-wind analysis and was used to estimate background wind error covariance and radar radial-wind observation error covariance from radar radial-wind innovation data.

15. SUBJECT TERMS
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